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Simulation and Analysis of Transient Stability in the Electrical System of PT. Semen Indonesia Aceh

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***ABSTRACT:** PT. Semen Indonesia is a state-owned company that is a well-known cement producer in Indonesia and plans to build the Semen Aceh factory. The Semen Aceh factory's electrical system utilizes two power sources: Alternative Electrical System 1 relies on PLN sources, while Alternative Electrical System 2 uses a 30 MW generator and two 25 MW generators. Therefore, it is necessary to conduct a transient stability analysis—including voltage stability, frequency stability, and rotor angle stability—during generator outages, motor activation, and short-circuit disturbances. The simulation results for alternative electrical system 2 indicate that generator disconnection causes system frequency instability. In a short-circuit situation at the 0.4 kV voltage level, the impact on stability is not significant, even though it causes a momentary voltage drop that subsequently returns to normal. Meanwhile, in the case of a short circuit at a voltage level of 6.3 kV, each voltage level value decreases following a three-phase short-circuit fault; however, after the disconnection of CB5-831MV081, the instantaneous voltage value rises to 108.35% and subsequently stabilizes at 97.08%. In the case of motor activation, the lowest voltage drop reached 65.78% and then stabilized at 91.46%.*

***KEYWORDS:** Transient Stability; Transient Fault; Rotor Angle.*

I. INTRODUCTION

A system is considered stable if there is a balance between the mechanical power from the generator's prime mover and the electrical power generated. Under balanced conditions, the generator operates at synchronous speed. Electrical power output is significantly influenced by load changes; if the load increases or decreases, the mechanical power generated by the prime mover must adjust. If the prime mover fails to adjust to load changes, the system becomes unstable.

Transient stability relates to large disturbances that occur suddenly, such as short circuits, sudden disconnection of the line using a circuit breaker, and sudden load changes. If such a large disturbance occurs and is not immediately addressed, it will cause the rotor angle to accelerate or decelerate, which can cause the generator to lose synchronization.

Transient disturbances have a significant impact on the stability of the electrical system at large industrial facilities such as PT. Semen Indonesia Aceh. Therefore, it is important to conduct a transient stability analysis of the electrical system at PT. Semen Indonesia Aceh in order to understand how stable

the system is when facing transient disturbances. In this study, the primary focus is on transient stability analysis, which includes voltage and frequency stability for alternative power system 1, as well as voltage, frequency, and rotor angle stability for alternative power system 2 during generator outages, motor starts, and short-circuit faults, along with an analysis of effective load shedding mechanisms to address disturbances when necessary.

II. LITERATURE REVIEW

A. ELECTRIC POWER SYSTEMS

An electric power system is a network consisting of various interconnected components designed to meet the demand for electrical energy. Generally, the scope of an electric power system includes power plants, electrical transmission, substations, and distribution networks. From the perspective of primary energy sources, power generation systems can be divided into two categories: those based on non-renewable energy sources and those utilizing renewable energy sources. Transmission lines are the pathways used to convey electrical energy from power plants to distribution stations. The distribution system serves to connect distribution substations with consumers, with its primary role being the delivery of electricity. The distribution system is divided into two parts: primary and secondary distribution. Voltage in the primary distribution system generally ranges around 20 kV, while in the secondary distribution system, the voltage is stepped down to below 1 kV[1] .

B. POWER SYSTEM STABILITY

When designing and operating electrical systems, system stability is of utmost importance. This is because the system is considered robust enough to manage energy fluctuations that arise, ensuring that equipment remains in synchronization. Stable operational conditions in an electrical grid require a balance between the mechanical energy input to the generators and the energy output from the system. Under such conditions, the generators will rotate at the same speed.[2]

Power system stability is defined as a state in which generators can operate in sync within the system and can react to disturbances under normal conditions. Additionally, the system is capable of returning to its initial state (equilibrium) when conditions return to normal. The ability of elements within the power system to maintain this balance is known as stability. Issues related to stability can be categorized into three types based on the characteristics and intensity of disturbances, namely[3] :

1. Rotor angle stability
   Rotor angle stability refers to the capacity of a number of machines interconnected in an energy system to maintain a synchronous condition[4] .
2. Frequency stability
   The system's ability to maintain a stable frequency is known as frequency stability, particularly when disturbances occur that cause an imbalance between energy production and load consumption.[4] .
3. Voltage stability
   The capacity of an electrical system to maintain stable voltage values at every bus in the network so that operations continue normally despite disturbances is known as voltage stability.[4] .

C. TRANSIENT STABILITY

Transient stability is a system's capacity to return to a stable or balanced state after experiencing a major disturbance. Consequently, the system may become unstable due to disturbances exceeding its capacity. Stability analysis in electrical systems covers types of disturbances such as[5] :

1. Sudden load fluctuations due to power plant outages.
2. Changes in the transmission network, such as short circuits and switching.

Today, electrical systems are far more extensive, and the connections between them are highly complex, involving hundreds of machines that interact through high-voltage networks connected to the power grid. The various problems analyzed include large disturbances that render linear methods inapplicable. Transient Stability issues can be divided into single-oscillation stability and double-oscillation stability. Single-oscillation stability is based on a simple generator model that does not include control systems. The analysis period generally lasts for the first second after a disturbance occurs. If the machines can be synchronized before the end of the first second, then the system can be considered stable[5] .

D. TRANSFORMER DATA

The transformer data required for simulation includes power transformers, current transformers, and voltage transformers. The detailed data for each transformer includes capacity, impedance, and transformer ratios for power transformers. Meanwhile, transformer ratios and reference current data are required for current transformers[6] .

1. Network Data
2. Input Load Data
3. Load data for each feeder

E. SHORT-CIRCUIT FAULT

A short-circuit fault is a conductive connection that occurs intentionally or unintentionally through a conductor or impedance with a sufficiently large potential difference. The maximum allowable voltage drop in an industrial electrical distribution system is 3% for lighting loads and 5% for other electrical loads; these percentages are adjusted based on the voltage supplied by the power source[7] . A three-phase short circuit is a fault that occurs when all three phase conductors come into contact. This fault can be caused by a fallen tree striking the power lines. Therefore, it is important to analyze the short-circuit fault current based on the location of the fault point on a 20 kV medium-voltage overhead line[8] .

III. RESEARCH METHOD

The research was conducted using a quantitative method based on secondary data sources. The sequence of steps in the research process is as follows:

1. Collection of secondary data
2. Modeling and Determination of Basic Values
   System modeling and parameter determination are performed using the Etap (Electrical Transient Analysis Program) software, which is designed to analyze, model, and manage electrical power systems in detail. After modeling the system in the software, data processing is carried out by inputting parameter values into the model.
3. System Modeling Simulation
   Simulating the system model after entering the equipment parameter values.
4. Analysis of Simulation Results
   Subsequently, an analysis of the simulation results is conducted in accordance with the

research problem and objectives, covering voltage and frequency transient stability in PT Semen's electrical system, as well as the transition time from transient to steady-state conditions.

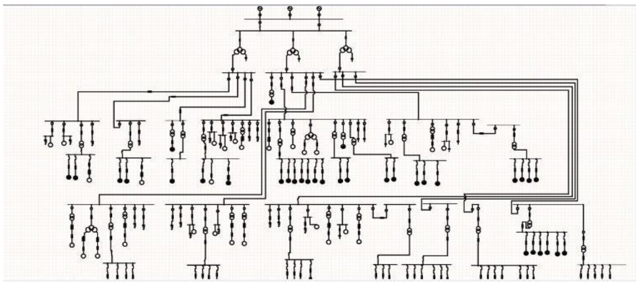

Fig 1. *Single-line diagram of* PT Semen Aceh

Figure 1 shows the layout of the alternative electrical system at PT. Semen Indonesia Aceh. In Figure 1, alternative power system 1 differs only in terms of its energy supply. The power system at PT. Semen Aceh has several voltage levels, namely 150 kV, 6.3 kV, and 0.4 kV for alternative power system 1, and 11 kV, 6.3 kV, and 0.4 kV for alternative power system 2. The power supply system includes 3 generator units, each with a capacity of 30 MW (841BG01) as *a swing unit* and 2 x 25 MW for voltage control in Alternative Power System 2. Meanwhile, for Alternative Power System 1, the power supply is connected to PLN with a total of 3,091 MVa and a 150 kV short-circuit rating. The total generating capacity at PT. Semen Aceh is 42.38 MW, with a total load of 39.39 MW.

IV. TRANSIENT SIMULATION AND ANALYSIS

A. CASE STUDY: TRANSIENT STABILITY SIMULATION

Tbl 1. Cases and Descriptions of Transient Stability Analysis

Case	Description	t (s)
	Alternative Electrical System 1	
0.4 kV	3-phase bus short circuit 831LV08	2
Short	*831LV08-CB1 open*	2.5
Circuit	3-phase busbar short circuit 831LV08	2
	831LV08CB1 open	2.5
6.3 kV	3-Phase Bus Short-Circuit 831MV08	2
Short	*831MV08-CB5 open*	2.5
Circuit	3-phase busbar short-circuit 831MV08	2
	831MV08-CB5 open	2.5
MS start	341FN01M01 *start*	2
	Alternative Electrical Systems 2	
Generator Fault	Generator 841BG02 *trip*	2
0.4 kV	3-phase short circuit on bus 831LV08	2
Short	*831LV08-CB1 open*	2.5
Circuit	3-phase short circuit on bus 831LV08	2
	831LV08-CB1 open	2.5
6.3 kV	3-phase short circuit on the 831MV08 bus	2
Short	*831MV08-CB5 open*	2.5
Circuit	3-phase short circuit on the 831MV08 bus	2
	831MV08-CB5 open	2.53
MS start	341FN01M01 *start*	2

B. SIMULATION OF FAULT CASES IN GENERATORS

Tbl 2. Rotor Response in Generator Fault Cases

Gen ID	Rotor angle before fault	Rotor angle after fault
841BG02	Fault	Fault
841BG03	21.7°	26.9 °

Tbl 3. Frequency Response in the Case *of a Generator Fault*

Frequency before the generator fault (%)	Frequency after generator fault (%)
	Unstable

Tbl 4. Voltage Response in *Generator Fault* Cases

Bus	Voltage before generator fault (%)	Voltage after the fault at the generator (%)
Main Bus	99.	Unstable
	99. 96.	Unstable Unstable

C. SHORT-CIRCUIT SIMULATION

1. Short-Circuit Simulation Case 0.4 kV Alternating Current Electrical System 1

Tbl 5. Frequency Response in a 0.70 kV Short-Circuit Case

Frequency before short circuit (%)	Maximum Frequency During Short Circuit (%)	Stable Frequency (%)
98	99.8	100

Tbl 6. Voltage Response in a 70 kV Short-Circuit Case

Bus	Voltage before fault (%)	Minimum voltage during short circuit (%)	Stable voltage (%)
System Bus	98.9402	99.3497	100.047
831MV012 831LV052	97.6493 99.6815	99.0761 95.9174	99.8415 96.8818

2. Simulation of a 6.3 kV Short Circuit Case (831MV081) Alternative Electrical System 1

Tbl 7. Frequency Response in the 22 kV Short-Circuit Case

Frequency Before Short Circuit (%)	Maximum Frequency During Short Circuit (%)	Stable Frequency (%)
100	100	100

Tbl 8. Voltage Response for a 22 kV Short-Circuit Case

Bus	Voltage before fault (%)	Minimum Voltage During Short Circuit (%)	Voltage Stable (%)
System Bus	99.9998	94.7188	100.056
	99.7907	93.9666	99.853
831LV052	96.8186	89.3594	96.896

3. Case Study: 0.4 kV Short Circuit (831LV081) Alternative Electrical System 2

Tbl 9. Rotor Angle Reaction in a 70 kV Short-Circuit Case

Gen ID	Rotor angle before the fault	Rotor angle after the fault
	20.76 °	20.77 °
	20.76 °	20.77 ℃

Tbl 10. Frequency Response in a 0.70 kV Short-Circuit Case

Frequency before short circuit (%)	Maximum Frequency During Short Circuit (%)	Stable frequency (%)
100	100.184	100.065

Tbl 11. Voltage Response for a 70 kV Short-Circuit Case

Bus	Voltage before fault (%)	Minimum Voltage During Short Circuit (%)	Stable voltage (%)
Main busbar System	99.9996	93.4756	100.068
831MV012	99.7741	92.6148	99.844
831LV052	96.8181	87.5544	96.904

4. Case Study: 6.3 kV Short Circuit (831MV081) Alternative Electrical System 2

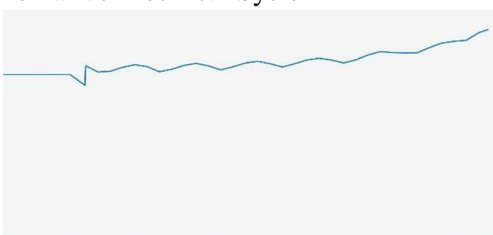

Fig 2. Rotor angle response of the system when generator 841BG02 disconnects from the system

Figure 2 illustrates that the rotor angle of the 841BG02 generator before the fault was 21.77 degrees, then oscillated until reaching a peak value of 27.66 degrees. After the fault, the rotors of generators 841BG02 and 841BG03 reached a stable value of 20.23 degrees.

Fig 3. Frequency response during a three-phase short-circuit fault

In Figure 3, it can be seen that the system's frequency response during a three-phase short-circuit fault at bus 831MV081 experiences a frequency increase up to 100.985%. This phenomenon is caused by the opening of CB5-831MV081, resulting in the loss of load under bus 831MV081. Consequently, the generation power becomes greater than the load demand. The frequency then reaches a stable condition at 100.37%. The frequency is considered stable in continuous operation if its value ranges from 99.17% to 100.83%.

1. Simulation of Alternative M Start Case 1

Fig 4. Voltage response during the starting of motor M532FN11

Figure 4 illustrates the voltage response when motor 341FN01M01 begins operation. Before the 341FN01M01 motor is activated, the voltage level on the bus is 101.92%. However, after the motor is activated, the voltage drops to 72.21% before eventually stabilizing at 91.58%. The conclusion of this evaluation is that the system voltage demonstrates stability because it remains within the standard range set by PLN.

2. Simulation of Alternative M Start Case 2

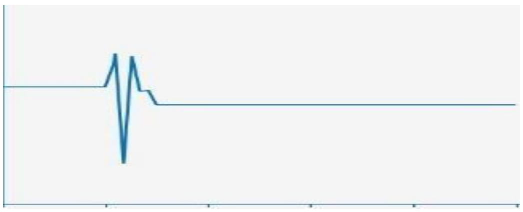

Fig 5. System rotor angle response during the startup of motor 341FN01M01

Figure 5 shows that the rotor angle positions of generators 841BG02 and 841BG03, which were previously at 27.08°, decreased to 12.21° during the disturbance, before eventually stabilizing at 27.08%.

Fig 6. Frequency response during the startup of motor 341FN01M01

Figure 6 presents a visualization of the system's frequency response during the startup of motor 341FN01M01. When motor 341FN01M01 begins operation, the system frequency drops to 97.912%. This drop is caused by significant power consumption by the motor over a short period of time. The frequency then gradually reaches a stable condition at 99.568%. Frequency stability during continuous operation is defined as a value within the range of 99.16% to 100.81%.

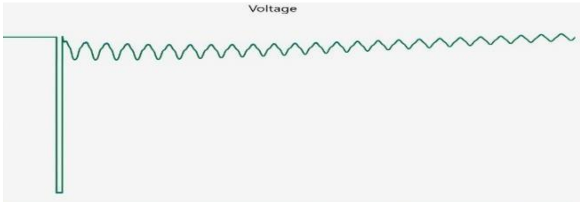

Fig 7. Voltage response when motor 341FN01M01 starts

Figure 8 shows the voltage response as the 341FN01M01 motor begins operation. On the 341FN01M01 bus, the voltage value before the motor began operation was 101.87%. However, after the motor began operation, the voltage dropped to 45.78%, before stabilizing at 91.457%. Based on this analysis, it can be concluded that the system voltage remains within the IEEE C37.106 standard range.

V. CONCLUSION

When the generator is disconnected, the system exhibits instability. In the case of a short-circuit incident on the 6.3 kV power grid (Alternative 1) (831MV081), the system remains stable. Conversely, for a short-circuit incident on the 0.4 kV power grid (Alternative 1) (831LV081), the system also remains stable. In the short-circuit scenario on the 0.4 kV Alternate 2 power grid, all voltage levels dropped following a three-phase short-circuit fault at 0.4 kV. However, after CB1-831LV081 was opened, the voltage at briefly reached 99.513% and gradually stabilized at 96.905%. In the event of a short circuit in the Alternative 2 power grid at 6.3 kV, all voltage levels also dropped following the three-phase short circuit at 6.3 kV; however, after CB5-831MV081 was tripped, the voltage briefly reached 108.359% and returned to a stable condition at 97.09%. In the case of motor startup, on the Alternative 1 power grid, the lowest voltage drop recorded was 72.20% with the system returning to stability at 91.57%, while on Alternative 2, the lowest voltage drop reached 65.79% and the system returned to stability at 91.456%.

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AUTHORS BIOGRAPHY AND CONTRIBUTIONS

Hartono, dilahirkan di Pati, 03 Januari 1976, menepuh Pendidikan S1 di Universitas Diponegoro jurusan Teknik elektro pada tahun 1994-2001, setelah itu melanjutkan Pendidikan S2 di Universitas Indonesia jurusan Teknik elektro pada tahun 2004-2007. Status pekerjaan sebagai dosen di universitas sultan ageng tirtayasa, bekontribusi pada penelitian sebagai pemvalidasi data pada penelitian simulasi stabilitas transien.